# Large Area Portable Neutron Detectors

## Helium-3 Alternatives

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***Abstract*— PartTec, Ltd. has, for the past 3 years, pursued the development of $^{3}$He alternative neutron detectors for applications such as border security, portal monitors and hand-held devices. This paper discusses PartTec's mobile, very large area, ruggedized and highly efficient neutron detector. The detector's construction and performance are outlined in the paper. The goals for development of the detector are to meet all performance standards of the ANSI N42.43 committee's publication, "American National Standard Performance Criteria for Mobile and Transportable Radiation Monitors Used for Homeland Security." The introductory model of PartTec's line of mobile neutron detectors has an active area of 3,600 cm$^{2}$, consists of 1,200 wavelength shifting fibers, 12 single anode photomultiplier tubes and 60cm x 60cm $^{6}$LiF:ZnS(Ag) scintillator sheets. The purpose of the paper is to introduce to the community the successful implementation of the use of LiF scintillator-based neutron detectors in real-world applications, showing that a commercially viable helium-3 replacement can now be developed. The paper discusses issues related to this detection technology including its performance, manufacture, availability, design flexibility, and cost.**

***Keywords-component; helium-3, alternative, ruggedized, mobile, neutron, detector, R&D 100***

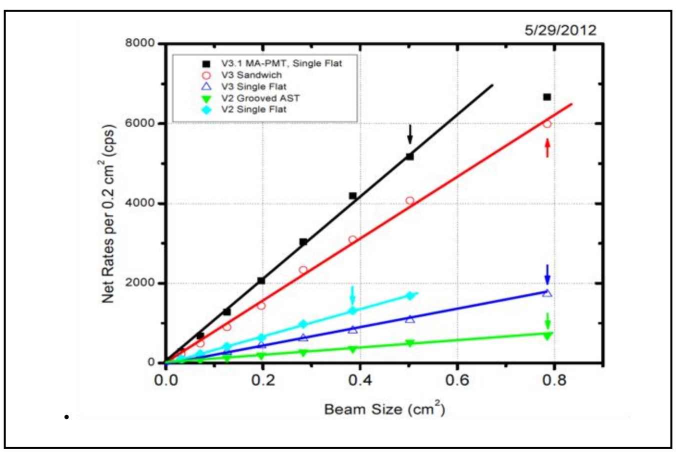


Chart 1. Performance changes of the wavelength-shifting, scintillator-based nuetron detector (courtesy of Oak Ridge National Laboratory)

## I. PartTec's Research Neutron Detector

The Large Area Mobile detector is a re-engineering effort, based upon the very successful product platform of PartTec's Research Neutron Detector, which, in collaboration with the Spallation Neutron Source (SNS) at the Oak Ridge National Laboratory (ORNL), won a 2012 R&D 100 award. That product, complete with electronics and analytical software, is manufactured through a license agreement between PartTec and ORNL. Its original design concept was created at ORNL for use in two of the diffractometer instruments at SNS. Both of those instruments required a modular, large area, high resolution, two dimensional, inexpensive, yet very efficient thermal neutron detector. The SNS design was improved for performance and manufacturability by PartTec, Ltd. PartTec now carries that detector in its Research Neutron Detector product line and manufactures it at the PartTec Engineering and Production facility in Linton, Indiana. The research and development efforts that support detector improvements are conducted at the PartTec Headquarters R&D facility in Bloomington, Indiana. PartTec has delivered 50 of these detectors to Oak Ridge since 2006, and will manufacture and install another 150 over the next five years.

PartTec and SNS re-designed the detector in 2011, producing the efficiency improvements as shown in Chart 1 and the cost improvements shown in Chart 2. In Chart 2, the development versions listed are in rough chronological order, left to right. Currently, SNS is reviewing data generated by the latest prototype, which uses a Multi-Anode Photomultiplier (MAPMT), to determine if there are other improvements that would be important to include in the re-design effort.

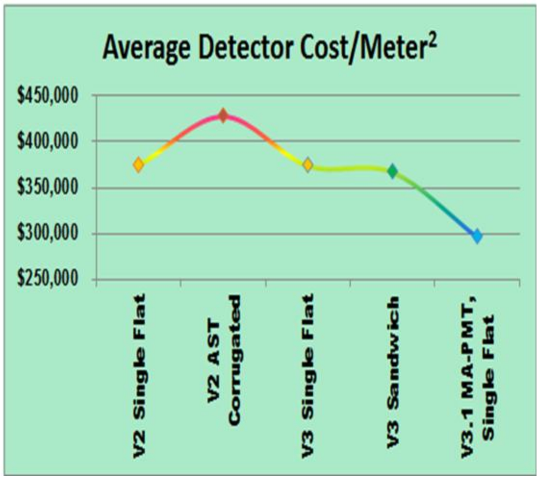


Chart 2. Estimated average cost per square meter of position sensitive, wavelength-shifting, scintillator-based neutron detectors

## II. The Radiological Security Market

The lack of affordable, commercial, off-the-shelf (COTS) neutron detectors is a serious concern for the Domestic Nuclear Detection Office (DNDO), the Department of Homeland Security (DHS) and the National Nuclear Security Agency (NNSA). A neutron signature associated with a vehicle or shipping container may indicate the presence of Special Nuclear Materials (SNM) such as plutonium and uranium. Plutonium is a prolific source of fission neutrons and an important element for detectors to locate. The presence of a large quantity of uranium can also be detected by its neutron signature [1]. It is difficult to effectively shield and transport these materials, making neutron detection a practical means of discovering the clandestine transport of SNM. Consequently, neutron detection is an essential aspect of the interdiction of radiological threats for homeland security purposes and the availability of COTS detectors is a basic need.

Historically, $^3$He-filled tube neutron detectors have been the "gold standard" for thermal neutron detection because $^3$He has a large capture cross-section for thermal neutrons (2800 barns) and weak gamma response. The detectors typically are robust and long-lived. Gamma discrimination is very important as it can be difficult to distinguish gammas from neutrons, which can result in high false alarm rates.

$^3$He tubes, containing several atmospheres of $^3$He, have been used for scientific research applications for decades, but the recently disclosed unavailability of $^3$He makes their continued ubiquitous use impractical. $^3$He tube detectors were adopted for and have been routinely used in Radiation Portal Monitors (RPMs). Detector sales for this application grew quickly after the September 11, 2001, terrorist attacks, resulting in the RPM being the largest user of the $^3$He inventory [2]. The increased draw on $^3$He inventory by DHS (for RPM's), SNS and new neutron research laboratories around the world has brought about a world-wide shortage of $^3$He gas [2]. Therefore, it is critical that cost-effective COTS neutron detectors, which do not use $^3$He, be immediately available to DNDO and to research scientists.

## III. Technical Approach

PartTec believes that ruggedizing and re-engineering its existing Research Neutron Detector technology, that has already been proven successful, is the most promising response to meeting the immediate need for an alternative to the $^3$He shortage. PartTec and ORNL will continue to cooperate in research and development to provide the international community a variety of options for neutron detection for the growing market demand.

### *A. PartTec's Current Line of Research Detectors*

PartTec has manufactured and sold scintillator-based, wavelength shifting fiber neutron detectors to SNS since 2006. This technology uses commercially available large flat sheets of $^6$LiF:ZnS(Ag) scintillator that absorb neutrons resulting in the emission of ~ 420 nm (blue) light [4]. That emitted light enters orthogonally through the cladding of the wavelength shifting (WLS) optical fibers. The WLS fibers contain phosphors that convert the 420 nm photons from the scintillator to 500 nm (green) photons. The re-emitted photons travel along the fiber to the fiber ends. The photons exit the fiber ends and are detected by Photo-Multiplier Tubes (PMTs) which generate an electronic pulse for each detected photon. The pulses are digitized, collected and analyzed. Several steps are taken within the electronics firmware and the data acquisition software to eliminate noise (or background) signals and various analyses are performed to determine that a neutron event has occurred versus a random non-neutron event such as a gamma ray event.

The operating characteristics of the PartTec Research Neutron Detector are: a detecting area of 0.36 $m^2$, a 5mm x 55mm pixel, a count rate capability of ~3 x $10^5$ n/s, a gamma rejection ratio of 1.8 x $10^{-6}$ and large scale modularity. Compared to $^3$He, for which supplies are unable to meet current demands, there is a virtually unlimited supply of $^6$Li. While the detector is approximately five times more sensitive to gammas than a $^3$He detector, its sensitivity is still relatively low at 1.8 x $10^{-6}$.[3]

The integration time for neutron-gamma discrimination and position resolution for the PartTec Research Neutron Detector is 3 μsec, resulting in a maximum count rate capability of ~300 KHz.

True to its mission of partnering in technology, PartTec has chosen to acquire and use an exclusive license for the electronics and software that are available exclusively to PartTec through a license from the Department of Energy (DOE). PartTec collaborated with SNS in the development of the technology over a five-year period through a DOE SBIR grant [5], and in March, 2010, licensed the exclusive world-wide rights to manufacture and market the technology.

*B. Parttec's Security Detector Development*

In 2009, PartTec began a major internally funded project to morph its existing Research Neutron Detectors into three new product lines, all of which are focused on security applications. Every product developed has the same performance goals: detection efficiency, gamma rejection, deployment ease and overall cost that must meet or exceed existing $^{3}$He tube detectors.

*C. Neutron Energy*

Consideration has been given to the results from recent studies at SNS comparing the detection efficiency and gamma sensitivity between the $^{3}$He tube detectors and the PartTec Research Neutron Detector as a function of neutron energy. These results were presented at the $^{3}$He Alternative Workshop [3]. The neutron capture cross sections for $^{3}$He, $^{6}$Li and $^{10}$B as a function of neutron energy, shown in Figure 1, drops by a factor of $10^{5}$ between 1 meV and 1 MeV. Therefore, a polyethylene or equivalent moderator surrounding the detector is required to achieve high detection efficiency as a function of energy. This method of moderation is used in the existing Radiation Portal Monitors and is acceptable to the security community. PartTec has adopted this method in all product lines.

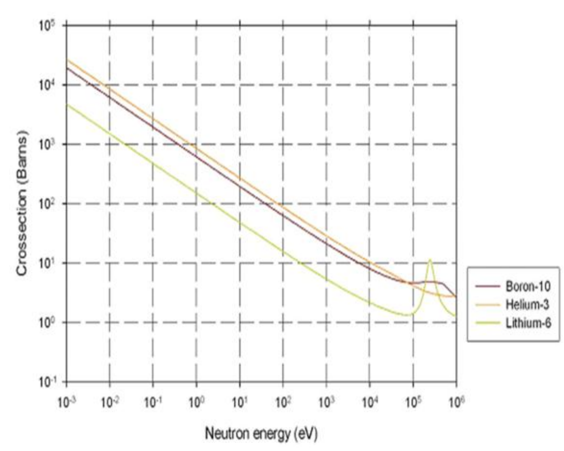


Figure 1. Neutron Capture Cross Section vs. Energy for $^{3}$He, $^{10}$B, and $^{6}$Li

*D. Discrimination and Efficiency*

In 2009, SNS conducted several studies including a comparison of the simulated Compton electron production between the $^{3}$He tube detector and the PartTec Research Neutron Detector with two gamma sources;10 mCi $^{60}$Co and 25 mCi $^{137}$Cs [3]. In addition, SNS measured the gamma sensitivity of the PartTec Research Detector compared to a SNS/Nomad Instrument $^{3}$He tube detector using a 4.4 mCi $^{137}$Cs source centered on the detectors at a distance of 42 cm to provide a 10 mR field. The results showed the $^{3}$He tube detector's gamma sensitivity to be 3.3 x $10^{-7}$ and the PartTec Research Neutron Detector's gamma sensitivity to be 1.8 x $10^{-6}$[3]. Though five times more sensitive to gammas than the tube detector, the PartTec Research Neutron Detector still met DNDO and ANSI N42.43 requirements for Security Detectors.

Furthermore, the SNS studies demonstrated that the PartTec Research Neutron Detector obtained the same neutron detection efficiency as a tube detector with 6.6 bar $^{3}$He [3], and thus had the potential to be developed into a viable neutron detector for Mobile and Transportable, Portal Monitor and Handheld systems for the detection of SNM.

*E. Ruggedization*

As a prelude to entering the security market, PartTec accepted an invitation by the Department of Homeland Security to supply a detector for testing in August, 2009. A PartTec Research Neutron Detector, "VULCAN" model, was taken to Los Alamos National Laboratory and left for testing. No modifications were made to the detector. Though it proved that it could detect neutrons and discriminate gammas, not surprisingly, this detector failed ruggedization tests, including those for EMF, temperature and humidity. In addition, PartTec learned that the data transfer methods for the security community are entirely different than for the research community, that position resolution is not a factor for security and that efficiency, discrimination, elimination of false positives, rugged operation, ease of use and ease of deployment using the customers' existing power and mechanical platforms were all extremely important. Most important, determined, were cost and availability.

In a collaborative project with the Global Nuclear Security Technology Division at the Oak Ridge National Laboratory, PartTec made modifications to the Research Neutron Detector's shielding, designed and added a surrounding moderator and substantially changed its detection and position resolution algorithms [6]. Based upon the promise shown in that work, PartTec and ORNL collaborated to develop a ruggedized large area detector beginning in September, 2011. That project led to the manufacture of a prototype of the PartTec Mobile Neutron Detector. The prototype was designed, manufactured and delivered for testing on December 31, 2011. The prototype detector has an active detection area of 60cm x 60cm, an estimated thermal neutron detection efficiency greater than 60%, and neutron-gamma discrimination estimated at greater than $10^{-6}$. The detector was tested at the Indiana University Cyclotron Facility, and outdoors at ORNL over the course of several days to monitor stability with respect to temperature and humidity, and sensitivity using a 200,000 n/s $^{252}$Cf source, both bare and in a 10x10x10 cm polyethylene block. By walking this source past the detector at speeds up to 2 m/s, we were able to demonstrate detection at source-detector distances up to 10 m. A follow-up design is calculated to increase the neutron detection efficiency for thermal neturons to over 90%.

In addition, this detector can be transported by land, sea or air. The prototype has been tested at ORNL, at the Indiana University Cyclotron Facility and was included in a second field trial in July, 2012. Preliminary results indicate that it passed all its tests in this field trial.

This PartTec Mobile Neutron Detector achieves the highest possible neutron absorption and light harvesting from the scintillator. All fiber ends are polished individually using PartTec's Diamond and Ice© polishing method which supports PartTec's continued emphasis and focus on increasing efficiency through increased photon harvesting.

## IV. Costs

Though larger than the PartTec Research Neutron Detector, the PartTec Mobile Neutron Detector is designed for manufacturability and with the requirement that it accurately and efficiently monitor the presence of neutron radiation. Therefore, the PartTec Mobile Neutron Detector is much simpler to assemble, requiring several man-weeks less effort, and uses only 12 PMTs rather than the 32 used by the PartTec Research Neutron Detector, thus reducing manufacturing costs.

## V. Conclusion

As the $^3$He crisis continues, the market will demand a more suitable, longer lasting alternative that has similar or better neutron detection efficiency. PartTec has responded by developing a reliable, durable, replacement for $^3$He-based neutron detectors that will benefit a variety of different sectors, including the Department of Homeland Security, the Department of Defense, national laboratories and global security organizations.

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